#10 9/14/02

PATENT
TH-1258 (US)
ERM:SWT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of Donald W. Allen et al Serial No. 09/625,893 Filed: July 26, 2000 SMOOTH SLEEVES FOR DRAG AND VIV REDUCTION OF CYLINDRICAL STRUCTURES	Group Art Unit: 3673 Examiner: K. Mitchell August 22, 2002

DECLARATION OF DR. DONALD W. ALLEN

I, Dr. Donald Wayne Allen declare as follows:

1. My name is Dr. Donald Wayne Allen. I am the Vortex-Induced Vibration and Suppression Team Leader for Shell Global Solutions (U.S.) and named inventor on the above-referenced patent application. I am more than 18 years of age, have not been convicted of a felony or a crime of moral turpitude, am of sound mind, and am competent to make this Declaration.

2. I received a B. S. in Mechanical Engineering from Texas A&M University in 1981, and a Ph. D. in Mechanical Engineering from Rice University in 1986. I have worked for Shell since August 1986 and am a Senior Staff Research Engineer. I consult with various Shell and non-Shell entities regard the potential vortex-induced vibration ("VIV") problems with various subsea structures. In this role, I have performed VIV analyses of offshore and subsea structures such as production platforms, risers, riser bases, jumpers, tendons, spars, and pipeline spans.

3. I have performed research directed to the characterization of VIV response prediction. I have also performed research directed to the development of VIV suppression devices, including various helical strake systems, fairing systems and shroud or covering systems. This research includes work performed at various Shell facilities located in Houston, Texas and at the Naval Surface Warfare Center, located in Caderock, Maryland.

4. I have authored and published a number of papers on the subject of VIV and its suppression. A list of my publications is attached hereto as Exhibit 1.

5. I have reviewed the Office Action that was issued in the above-referenced application and believe that the Examiner is in error as to (a) various hydrodynamic problems addressed and (b) what the references teach.

CALM DOWN

6. Laminar flow, for an incompressible fluid such as water or air at low Mach numbers, may be defined as the streamline flow of a fluid in which the fluid moves in layers without fluctuations or turbulence so that successive particles passing the same point have the same velocity. Laminar flow about a body typically takes place at low fluid velocities, high viscosities, low densities or small body dimensions. Conversely, turbulent flow is a form of fluid flow in which the particles of the fluid move in a disordered manner in irregular paths, resulting in an exchange of momentum from one portion of a fluid to another. For flow past a an object with a round, rectangular, or otherwise bluff cross section, turbulent flow takes over from laminar flow when high values of Reynolds number are reached. The Reynolds number itself a dimensionless parameter and may be defined as:

$$R_e = \frac{\rho U l}{\mu} = \frac{U l}{\nu}$$

where ρ is the fluid density, μ is the dynamic viscosity coefficient, ν is the kinematic viscosity coefficient (μ/ρ), U is the characteristic velocity of the fluid and L is a length parameter, such as the diameter of a pipe or diameter or length of a body, in the case of flow external to a body. As the Reynolds number increases, the flow past a body becomes increasingly turbulent. In the hydrodynamic context, drag is the force exerted on a body in a direction parallel to the fluid flow.

7. Vortex shedding is a phenomenon that occurs in flow past a cylinder. As the fluid approaches the cylinder, the fluid closest to the cylinder wall is impeded by the friction on the cylinder surface, hence the region between the wall and where the velocity is close to that of the free stream is known as the boundary layer. As the boundary layer fluid proceeds around the cylindrical surface, the friction of the surface causes the boundary to flow increasingly slower, eventually bringing it to a halt. The boundary layer then separates from the cylinder, forming a shear layer. Because the fluid flowing in outer portion of the shear layer is flowing faster than the inner portion of the layer, the layer rolls up into a vortex. This process of separation and formation of vorticies can occur in both the laminar and turbulent flow regimes.

8. As the Reynolds number increases, the vorticies become increasingly unstable and start separating or shedding in close proximity to the cylindrical body. When this occurs, an alternating vortex or von Karman street is formed. Where the cylindrical body is free to move, the alternating forces will cause the cylinder to vibrate. If the cylinder vibrates at its natural frequency it will tend to lock into this vibration mode. If the mode shape is a bending mode (typcial of a long slender tubular such as a riser or pipeline) then the cylinder will see increased bending stress, which can induce fatigue in the body, thereby decreasing its serviceable life.

9. In reviewing the Office Action, I further noted that in many instances, the Examiner correctly noted that a smoother surface can result in a reduction in friction of fluid flowing around a body, thereby reducing drag. The Examiner reaches the conclusion that a

reduction in drag will result in a reduction in VIV. VIV, while related to, differs from drag. While it is true that an increase in VIV can result in an increase in drag, it does not necessarily follow that a decrease in drag results in a decrease in VIV. It is known that certain structures that increase drag on a body can result in a decrease in VIV. The application of helical strakes or fins on cylindrical bodies results in an increase in drag. However, the helical strakes have the effect of breaking up vortex formation, thus decreasing VIV. In US Patent 6,309,141, in which I am named a co-inventor, the fact that an increase in drag can, in certain circumstances, result in reduced VIV, is reported at column 3, lines 18 – 27. Thus, it does not follow that a reduction in drag necessarily results in a reduction in VIV.

10. I have reviewed the Examiner's rejections and the prior art relied upon for the rejections. The Examiner states that U.S. Patent 4,470,722 to Gregory ("Gregory '722") teaches a cylindrical housing element for use with a marine production facility that has an exterior coating of fiberglass or plastic. The Examiner then states that while Gregory does not explicitly disclose an ultra-smooth cylinder, the fact that the present application states that the ultra-smooth surface could be provided by sleeves made of copper, carbon fiber, rubber or any sufficiently smooth material. The present application discloses an example of an ultra-smooth surface as having a K/D of 5.1×10^{-5}. The Examiner then argues that since Gregory discloses fiberglass, it must inherently have a K/D of 5.1×10^{-5} or less.

11. This assumption is in error, as it does not follow that fiberglass or plastic has a K/D of the type claimed in the present application. In the article *Vortex-Induced Vibration Tests of a Flexible Smooth Cylinder at Supercritical Reynolds Numbers*, May 1997, (the "Allen article") I discussed tests utilizing ABS or PVC plastic bodies. The K/D ratios discussed therein were in the range between 8.86×10^{-5} to 1.51×10^{-4}. Both the ABS and PVC cylinders required special surface preparation prior to the tests. In this instance, the ABS pipe was purchased commercially, chosen from numerous samples for its surface smoothness (i.e. lack of scratches and scuffs that typically accompany commercially purchased plastic pipe or tubing), and specially wrapped for transport to realize the K/D ratio set forth in the article. Similarly, the PVC was purchased commercially, chosen out of numerous samples for its surface smoothness, specially wrapped for transport purposes, and then wiped with an acetone to realize the smoothness described in the article. Contrary to the Examiner's statement, it does not follow that because Gregory '722 discloses fiberglass that the fiberglass would have the K/D of the claimed invention. In fact, in the experiments conducted in which this discovery was made, a fiberglass pipe without any modifications to its surface sustained very high VIV. The discovery was made when a fiberglass pipe was surface ground to an extremely smooth finish. Only then did was the VIV greatly reduced.

12. The Examiner also rejected claims 1 and 4 based on the Allen article stating that the Allen article teaches a method and system for controlling drag and VIV. Specifically at page 683 with reference to Fig. 4, the discussion was related to stationary cylinders in which a "strongback" was inserted in order to keep the pipe from vibrating. With the strongback inserted, the pipe was not free to move and did not undergo VIV. The tests dealing with the strongback pipe studied the relationship between the Reynolds numbers and the drag coefficient. It was posited that the surface smoothness of the pipe accounted for the

differences between the pipe being studied and data from existing references which were also for stationary cylinders.

13. The Allen article talks about VIV beginning at page 683, second column, first full paragraph. Therein, the ABS cylinder, with k/D in the range of 1.21 – 1.51 x 10^{-4} (see page 681, col. 1, last full paragraph) was tested without a strongback and was free to vibrate. As noted, the VIV increased, as did drag. In Fig. 6, the smooth PVC cylinder, having a k/D in the range of 8.86 x 10^{-5} to 1.09 x 10^{-4} was tested without a strongback. As noted therein, it displayed "substantial vibration and significant increased drag due to the vibrations." The conclusions are that for flexible and stationary cylinders in water with an Re over 1.5 x 10^{6}, the results indicate that

> a) small levels of roughness can have a tremendous effect on the drag coefficient of supercritical Reynolds number flow; and
> b) significant VIV response is observed at supercritical Reynolds numbers and is accompanied by substantial increase in drag.

14. There is nothing in the Allen article that suggests that an ultra-smooth surface as claimed in the present application is capable of reducing VIV in the ranges demonstrated. All flexible samples underwent significant VIV displacement over a broad range of Reynolds numbers.

15. The Examiner also cited U.S. Patent 6,206,614 and articles by Sellens and Smith are grounds for rejecting the claims of the patent. The Blevins '614 patent teaches a cylindrical sleeve and a method for controlling VIV by means of spacing of the columns. (Col. 4, lines 13 – 45). The Examiner then goes on to state that the Sellens article, the CE/ME 101 handout and the Smith article teach that smooth surfaces create less turbulent flow. It is also stated that the definition of relative roughness appearing at page 2 of the Sellens article is equivalent to the K/D ratio described in the present application and relates this to the drag coefficient, Reynolds number and relative roughness. I do not disagree. This is work that was similar to that discussed with reference to Fig. 4 of the Allen article.

16. While the Sellens and Allen articles do discuss surface smoothness and its effect on the drag coefficient over a range of Reynolds numbers, neither article suggests or teaches that surface smoothness has a significant effect on VIV suppression. As noted above, in discussion of Fig. 5 (pipe free to vibrate), the sample saw a significant VIV response in terms of displacement over a broad range of Reynolds numbers.

17. The CE/ME 101 handout is cited as teaching that relative roughness increases the turbulent drag and flow over cylinders. The Van Dyke reference merely identifies the "[e]ffect of rough surface or turbulent free stream" as opposed to that portion of the graph relating to turbulent boundary layers. While there is a depiction of a von Karman vortex street at Re = 140, there is no discussion with respect how varying degrees of surface roughness might suppress VIV (interestingly enough, at Re = 140 the flow past a cylinder is in fact completely laminar). Similarly, the *Drag of Blunt Bodies and Streamlined*

Bodies and the email from Professor Smits all address the very same issue – the reduction of drag over a range of Reynolds numbers can be a function of the smoothness of the surface. None of them address a reduction in VIV as a function of smoothness.

18. While it is true that a significant VIV response will increase the drag seen by a cylindrical body (see Allen article at 684), it does not follow that a reduction in drag will necessarily result in suppression of VIV. The Allen article, Mech 441, CE/ME 101, *Drag of Blunt Bodies and Streamlined Bodies* and Smits article do not suggest that an ultra-smooth surface can operate to significantly decrease VIV as claimed in the present invention.

I am aware that willful false statements and the like are punishable by fine or imprisonment, or both under Title 18 U.S.C. §1001 and may jeopardize the validity of the application or any patent issuing hereon. All statements made herein are made based on my own knowledge are true and that all statements made on information and belief are believed to be true.

Donald W. Allen, Ph.D.

D. Allen

Date: 8-22-02

FIGS. 15-16 illustrate test results demonstrating the surprising practicality and effectiveness of ultra-smooth surfaces. These tests were conducted in a tow tank environment with the marine element towed to develop relative motion between the test subject and the water. FIG. 15 illustrates transverse root-mean-square (RMS) displacement as a function of the Reynolds number for an ultra-smooth cylinder and for relatively rough cylinders representing marine elements. FIG. 16 illustrates drag coefficient as a function of Reynolds number for the same samples. The dimensionless roughness parameter K/D for these samples were:

C1

In the Claims

Please amend the claims 2, 3, 5 and 6 to read as follows:

Blevins - VIV does suppression

2. A method of controlling drag and vortex induced vibration about a substantially cylindrical marine element by providing an ultra-smooth surface coating about the cylindrical element having a K/D ratio of 1.0×10^{-4} or less where:

K is an average measured surface peak to trough peak distance; and

D is an effective outside diameter of the cylindrical element including the coating.

C2

3. A method of controlling drag and vortex induced vibration about a substantially cylindrical marine element by providing an ultra-smooth surface substantially cylindrical sleeve about the cylindrical element having a K/D ratio of 1.0×10^{-4} or less where:

K is an average measured surface peak to trough peak distance; and

D is an effective outside diameter of the cylindrical element, including the sleeve.

5. A system for controlling drag and vortex induced vibration comprised of a substantially cylindrical marine element having an ultra-smooth coating material with a K/D roughness parameter of 1.0×10^{-4} or less where:

K is an average measured surface peak to trough peak distance; and

D is an effective outside diameter of the cylindrical element including the coating.

C3

6. A system for controlling drag and vortex induced vibration comprised of a substantially cylindrical marine element having an ultra-smooth substantially cylindrical sleeve surrounding the marine element with a K/D roughness parameter of 1.0×10^{-4} or less where:

K is an average measured surface peak to trough peak distance; and

D is an effective outside diameter of the cylindrical element including the cylindrical sleeve.

#2 - Houghton Mifflin roughness not equivalent Ra or Rz -

Please amend the paragraph beginning at Page 8, line 3 to read as follows:

Substantial reduction in VIV can be observed where K/D is less than about 1.0×10^{-4} and is most pronounced at about 1.0×10^{-5} or less for fairly uniform roughness densities. [A higher K/D ratio may allow achieving the same] Similar results may be achieved where the roughness density decreases, even though the overall K/D ratio may increase.

Please amend claims 1 – to read as follows:

1. (First Amended) A method of controlling drag and vortex induced vibration in a substantially cylindrical element comprising providing an ultra-smooth surface about the cylindrical element having a K/D ratio of 1.0×10^{-4} or less where:

K is an average measured surface peak to trough distance; and

D is an effective outside diameter of the cylindrical element.

2. (First Amended) [A] The method of controlling drag and vortex induced vibration in accordance with Claim 1, wherein providing the ultra-smooth surface comprises providing a coating about the cylindrical element [having a K/D ratio of about 1.0×10^{-4} or less] where D is an effective outside diameter of the cylindrical element, including the coating[:

K is the an average peak to trough distance; and

D is the effective outside diameter of the cylindrical element, including the coating.

3. (First Amended) [A] The method of controlling drag and vortex induced vibration in accordance with Claim 1 wherein providing the ultra-smooth surface comprises providing a substantially cylindrical sleeve about the cylindrical element [having a K/D ratio of about 1.0×10^{-4} or less] where D is an effective outside diameter of the cylindrical element, including the sleeve[:

K is the average peak to trough distance; and

D is the effective outside diameter of the cylindrical element, including the sleeve].

4. (First Amended) A system for controlling drag and vortex induced vibration, comprising:

a substantially cylindrical marine element[; and] having

an ultra-smooth effective surface [about the substantially cylindrical marine element] with a K/D roughness parameter of about 1.0×10^{-4} or less, where:

K is an average measured surface peak to trough distance; and

D is an effective outside diameter of the cylindrical element.